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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

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☐ *Additional inventors are being named on the _____ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (280 characters max)

METHOD AND APPARATUS FOR SMOOTHING OVERALL QUALITY OF VIDEO TRANSPORTED OVER A WIRELESS MEDIUM

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ENCLOSED APPLICATION PARTS *(check all that apply).*

☒ Specification *Number of Pages* 23
☐ CD(s), Number ____
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Other (specify) ____
☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT *(check one)*

☐ Applicant claims small entity status. See 37 CFR 1.27.
☐ A check or money order is enclosed to cover the filing fees

FILING FEE AMOUNT ($)

☒ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 14-1270 — 160.00
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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.
☐ Yes, the name of the U.S. Government agency and the Government contract number are: _____.

Respectfully submitted,
SIGNATURE ____________
Date November 13, 2003

TYPED or PRINTED NAME Daniel J. Piotrowski
REGISTRATION NO.: 42,079 *(if appropriate)*
Docket Number: US030448

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

frame basis. Since resources are finite, processing may not be completed for a given level of output quality by the deadline for the completion of this output processing, i.e., a deadline miss occurs. Each deadline miss results in severe artifacts in the output. Due to the wireless media nature, the number of layers received for a given frame varies over time, which restricts the number of quality levels that can be chosen for the frame. In a preferred embodiment, every time a media frame is received, e.g., a video frame, and must be displayed, the number of received layers is inspected. The maximum number of layers that can be processed is determined by the number of received layers for a frame and the time that the CPU is available to process the layers of that frame with minimal risk of missing the corresponding deadline. However, quality level changes may result in perceivable artifacts. By minimizing the number of quality level jumps over time, i.e., smoothing the received images over time, the user views an image having a fairly stable quality. This smoothing is done, in a preferred embodiment, by setting up a Markov chain and defining a value function. Quality level changes that are not caused by the network conditions yield much negative value. Quality level changes that are caused by network fluctuations yield zero value in the case of quality drop. Showing no image at all receives the highest penalty. On the other hand, a higher number of processed layers yields a higher value.

By playing many videos with realistic packet losses a layer selection procedure has been developed that is optimized with respect to the value function. The optimized layer selection function developed in this manner, is used to determine the number of layers that need to be displayed as a function of the number of received layers for a given frame and for the preceding frames.

There are a number of approaches that deal with optimizing resource consumption and maximizing output quality. One is the approach of the present invention to apply scalable video algorithms to the decoding of scalable video. A quality level is defined as a number of layers to be processed. ~~Prior art~~ algorithms assume a stable input (like DVD). Stable input means that there is no loss of information during transmission, thus it implies that during decoding ~~of the video data~~ any quality level can be chosen. The

internal setting for resolving a trade-off between resource usage and output quality. FIG. 1 illustrates the basic concept of a scalable video processor with a control mechanism 102 influencing the behavior of a scalable application 101 by means of a set of parameters 103. The use of scalable applications to accomplish video processing allows parts of the application to be readily scaled so that output qualities can be achieved thereby enabling resource consumption to be balanced against output quality.

Consider a video decoder as a scalable video application (SVA). This video decoder can be controlled by varying its internal settings to produce an output video stream of variable quality. As illustrated in Table 1, the decoder processes only the base layer when it operates at the lowest quality level. With the increase of the quality level, the decoder increases the number of layers to be processed, as well as the processing time (and, obviously the resource consumption).

Quality level	Number Of Layers To Be Processed
q_0	BL
q_1	$BL+EL_1$
q_2	$BL+EL_1+EL_2$
...	...
q_n	$BL+EL_1+EL_2+\ldots+EL_N$

TABLE 1

However, not all the layers are always available. Given that the decoder receives the layers from a network, there is no guarantee for the number of layers input to the decoder at any moment in time. Therefore, it is uncertain what number of layers will be processed next. Information about the number of available layers can be obtained from the input buffer.

In general the processing by the scalable application of the present invention is described as follows. The application fetches a unit of work (frame) from an input

minimizes both the number of deadline misses and the number of quality level changes, while maximizing the quality level.

According to the invention, this problem is modeled as a Markov decision problem. The model is based on calculating relative progress of an application at its milestones. Solving the Markov decision problem results in a quality level control strategy that can be applied during run time while incurring little overhead.

Consumer terminals, such as set-top boxes and digital TV-sets, are required by the market to become open and flexible. This is achieved by replacing several dedicated hardware components, performing specific media processing applications, by a central processing unit (CPU) on which equivalent media processing applications execute. Resources, such as CPU time, memory, and bus bandwidth, are shared between these applications. Here, preferably only the CPU resource is considered.

At each milestone, the relative progress of the application is calculated. Here, the relative progress at a milestone is defined as the time until the deadline of the milestone, expressed in deadline periods.

Relative progress at milestones can be calculated as follows. Assume, without loss of generality, that the application starts processing at time t=0. The time of milestone m is denoted by c_m. Next, the deadline of milestone m is denoted by d_m. The deadlines are strictly periodic, which means that they can be written as

$$d_m = d_0 + m*P$$

where P is the period between two successive deadlines and d_0 is an offset. The relative progress at milestone m, denoted by ρ_m, is now given by

$$\rho_m = \frac{d_m - c_m}{P} = m - \frac{c_m - d_0}{P} \qquad (1)$$

To illustrate the calculation of relative progress, consider the example timeline shown in FIG. 2. In this example, P=1 and d_0=1. The relative progress at milestones 1 up

progress intervals

$$\pi_k = \left[\frac{kp}{n}, \frac{(k+1)p}{n}\right), \text{ for k=0,....,n-1.}$$

The lower bound and the upper bound of a progress interval π is denoted by $\underline{\pi}$ and $\overline{\pi}$, respectively.

At each milestone, a decision must be taken about the quality level at which the next unit of work will be processed. Hence, the set of decisions that can be taken in a state, i.e., in the Markov decision problem, corresponds to the set of quality levels at which the application can run. This set is denoted by Q.

Every quality level corresponds to the number of layers that are processed. Therefore, it is not possible to choose the quality level which requires decoding more layers than there are in the input buffer for a given frame. Thus the maximal quality level that can be chosen is given by the number of layers received and is defined by maxq(i).

Quality level changes are also taken into account, thus at each milestone the previously used quality level must be known. This can be realized by extending the set of states with quality levels. Therefore, a state i is defined by

- the relative progress interval in state i, denoted by π(i);
- the maximal quality level that it is possible to choose for the next unit of work in state i, denoted by maxq(i);
- the previously used quality level in state i, denoted by q(i).

Therefore, the set of states becomes Π x Q x Q.

A second element of which Markov decision problems consist is a set of transition probabilities. Let p_{ij}^q denote the transition probability for making a transition from a state i at the current milestone to a state j at the next milestone, if quality level q is

Then it is derived:

$$Y_{\pi,\rho_m,q} = \begin{cases} P(\rho_{m+1} < \overline{\pi}) = 1 - P(\rho_{m+1} \geq \overline{\pi}) & \text{if } \pi = \pi_0 \\ P(\rho_{m+1} \geq \underline{\pi}) & \text{if } \pi = \pi_{n-1} \\ P(\underline{\pi} \leq \rho_{m+1} < \overline{\pi}) = P(\rho_{m+1} \geq \underline{\pi}) - P(\rho_{m+1} \geq \overline{\pi}) & \text{otherwise.} \end{cases}$$

Let F_q denote the cumulative distribution function of X_q and make a pessimistic approximation of ρ_m by choosing the lowest value in the interval

$$\widetilde{\rho}_m = \underline{\pi}(i) \tag{3}$$

Given the above, the probabilities p_{ij}^q can be approximated by

$$\widetilde{p}_{ij}^q = \begin{cases} Y_{maxq_m, maxq_{m+1}} * \left(1 - F_q\left(b\left(1 - \overline{\pi}(j) + \underline{\pi}(i)\right)\right)\right) & \text{if } \pi(j) = \pi_0 \\ Y_{maxq_m, maxq_{m+1}} * F_q\left(b\left(1 - \underline{\pi}(j) + \underline{\pi}(i)\right)\right) & \text{if } \pi(j) = \pi_{n-1} \\ Y_{maxq_m, maxq_{m+1}} * F_q\left(b\left(1 - \underline{\pi}(j) + \underline{\pi}(i)\right)\right) - F_q\left(b\left(1 - \overline{\pi}(j) + \underline{\pi}(i)\right)\right) & \text{otherwise.} \end{cases}$$

The more progress intervals are chosen, the more accurate the modeling of the transition probabilities is, as the approximation in (3) is better.

A third element of which Markov decision problems consist is revenues. The revenue for choosing quality level q in state i is denoted by r_i^q. Revenues are used to implement the three problem objectives.

First, the quality level at which the units of work are processed should be as high as possible. This is realized by assigning a reward to each r_i^q, which is given by a function u(q). This function is referred to as the utility function. It returns a positive

is shown in FIG. 4. This FIG. illustrates that, for example, if the relative progress at a particular milestone is equal to 1, and if the previously used quality level is q_3 and the maximum quality level for the next frame is q_3, then quality level q_3 should be chosen to process the next unit of work, i.e., the next frame.

Without loss of optimality, so-called monotonic control strategies can be used, i.e., per previously used quality level it can be assumed that a higher relative progress results in a higher or equal quality level choice. Then, for storing an optimal control strategy, per previously used quality level only the relative progress bounds at which the control strategy changes from a particular quality level to another one have to be stored. A control strategy therefore has a space complexity of $O(|Q|^2)$, which is independent of the number of progress intervals.

The Markov decision problem can be solved off-line, before the application starts executing. Next, we apply the resulting control strategy on-line, as follows. At each milestone, the previously used quality and the maximum quality levels are known, and the relative progress of the application is calculated. Then, the quality level at which the next unit of work is to be processed is looked up. This approach incurs little overhead.

As input for the experiments an MPEG-2 Signal to Noise Ratio (SNR) decoding trace file of a video sequence consisting of 120000 frames is used. This trace file contains for each frame the processing time required to decode it, expressed in CPU cycles on a TriMedia, in each of four different quality levels, labeled q_0 up to q_3 in increasing quality level order. That is, the number of enhancement layers was set to 3 and the bit-rate for all layers is equal.

As a first step in the evaluation of the present invention, an assumption was made that the probabilities of transition from one maximal quality level to another are equal. Therefore, at milestone m the variable

$Y_{maxq_m, maxq_{m+1}}$ has the same value for any pair $maxq_m$ and $maxq_{m+1}$.

The first test used a budget of 40 ms and maximum quality level, assuming that network throughput is sufficient for delivery of all layers. Table 2 contains the changes in quality levels for the scalable application of the present invention. Table 3 contains the changes in quality levels for the straightforward application. As shown in Table 2 and Table 3, the straightforward algorithm makes a change in the quality level on average every 4th frame, which is 1300 times the number of changes made by the present invention. At the same time, the average quality for the scalable application of the present invention is higher than for the straightforward application, as illustrated in Table 4, which illustrates the percentage of quality level usage.

	To q_0	To q_1	To q_2	To q_3	Total
From q_0	-	1	0	0	1
From q_1	0	-	5	0	5
From q_2	0	1	-	11	12
From q_3	0	2	4	-	6
					24

TABLE 2 - Changes of Quality Levels for the Scalable Application in Test 1

	To q_0	To q_1	To q_2	To q_3	Total
From q_0	-	259	0	0	259
From q_1	34	-	321	0	355
From q_2	47	57	-	408	512
From q_3	100	129	129	-	358
					1484

TABLE 5 - Changes of Quality Levels for the Scalable Application in Test 2

	To q_0	To q_1	To q_2	To q_3	Total
From q_0	-	2781	2304	5845	10930
From q_1	2780	-	1500	1993	6273
From q_2	2659	1205	-	44	3908
From q_3	6219	2056	25	-	8300
					29411

TABLE 6 - Changes of Quality Levels for the Straightforward Application in Test 2

1. quality level is maximized;
2. deadline misses are minimized; and
3. quality level changes are minimized,

taking into account the maximum quality level determined by the number of received layers. Post processing was not taken into consideration.

Restating these objectives, a quality level control strategy was developed for a scalable media processing application, which had been allocated a fixed CPU budget such that it minimized both the number of deadline misses and the number of quality level changes, while maximizing the quality level. A parameter in the model is the number of quality level changes. the fewer the number of changes the smoother the image viewed.

FIG. 8 illustrates a system 1200 according to the invention in a schematic way. The system 1200 comprises memory 1202 that communicates with the central processing unit 1210 via software bus 1208. Memory 1202 comprises computer readable code 1204 designed to determine the amount of CPU cycles to be used for processing a media frame as previously described. Further, memory 1202 comprises computer readable code 1206 designed to control the quality level of the media frame based on relative progress of the media processing application calculated at a milestone. Preferably, the quality level of processing the media frame is set based upon a Markov decision problem that is modeled for processing a number of media frames as previously described. The computer readable code can be updated from a storage device 1212 that comprises a computer program product designed to perform the method according to the invention. The storage device is read by a suitable reading device, for example a CD reader 1214 that is connected to the system 1200. The system can be realized in both hardware and software or any. other standard architecture able to operate software.

FIG. 9 illustrates a television set 1310 according to the invention in a schematic way that comprises an embodiment of the system according to the invention. Here, an antenna, 1300 receives a television signal. Any device able to receive or reproduce a television signal like, for example, a satellite dish, cable, storage device, internet, or

CLAIMS:

1. A method of setting a quality level of an output image of a media frame by a media processing application, comprising the steps of:

determining an amount of resources to be used for processing the media frame;

controlling the quality level of the output image based on

i. relative progress of the media processing application calculated at a milestone,

ii. a maximal quality level that is possible to choose for the output image,

iii. a previously used quality level of an output image, and

iv. a maximum quality level based on the number of received layers

2. The method of claim 1, wherein the quality level is chosen based on a minimum of the highest quality level possible for processing the next frame and a highest quality level required to maintain the quality of the output image.

3. The method of claim 1, wherein:

the step of controlling the quality level of the media frame is modeled as a Markov decision problem comprising a set of states, a set of decisions, a set of transition probabilities and a set of revenues;

solving the Markov decision problem to derive an optimal strategy; and

determining the number of layers of the media frame that are decoded based upon this solution.

4. The method of claim 3, further comprising the steps of:

defining the set of states to comprise the relative progress of the media processing application at a milestone and the previously used quality level;

defining the set of decisions to comprise a plurality of quality levels that the media processing application can provide;

8. The system of claim 7, wherein:

the set of states comprises the relative progress of the media processing application at a milestone and a previously used quality level of a previous media frame;

the set of decisions comprises a plurality of quality levels that the scalable media processing application can provide;

the set of transition probabilities comprises a probability that a transition is made from a state of the set of states at a current milestone to another state of the set of states at a next milestone for a given quality level of the plurality of qualities; and

the set of revenues comprises a positive revenue related to a positive quality level of the media frame, a negative revenue related to a deadline miss and a negative revenue related to a quality level change.

9. A computer program product designed to perform the method according to claim 1.

10. A storage device comprising a computer program product according to claim 9.

11. A television set comprising a system according claim 5.

12. A set-top box comprising a system according claim 5.

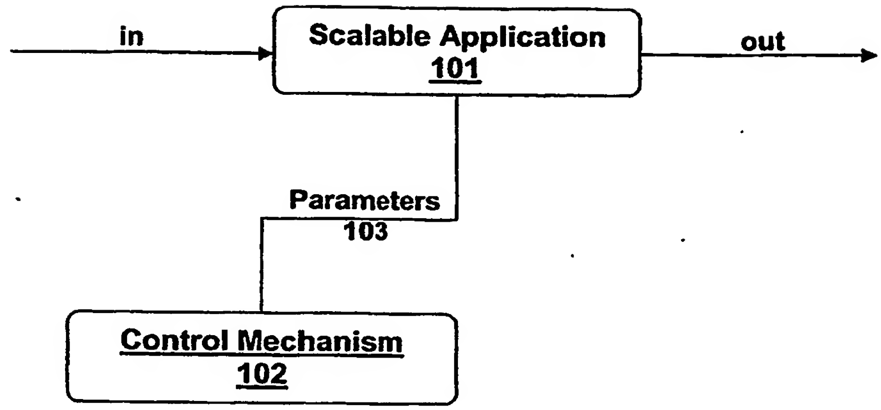

in
Scalable Application
101
out
Parameters
103
Control Mechanism
102

FIG. 1

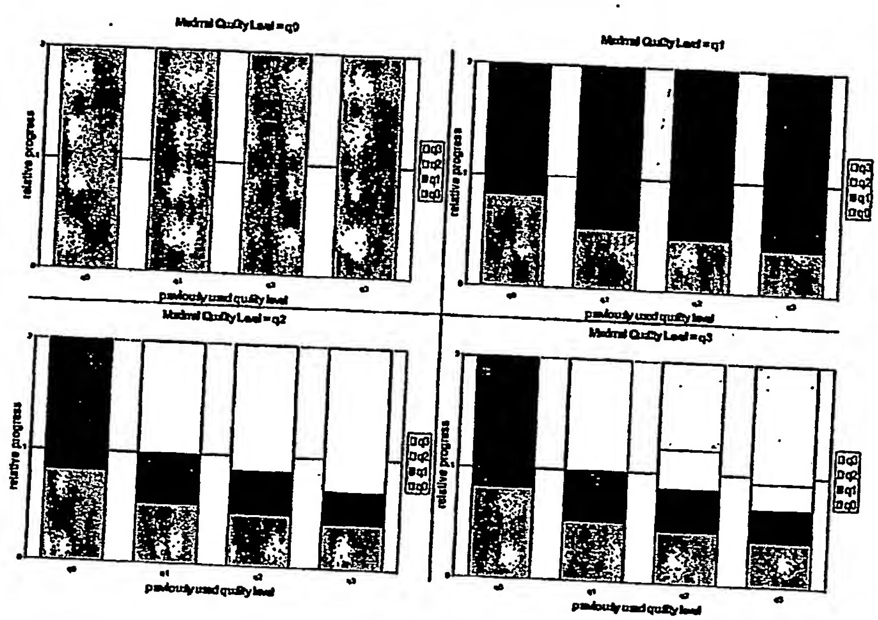
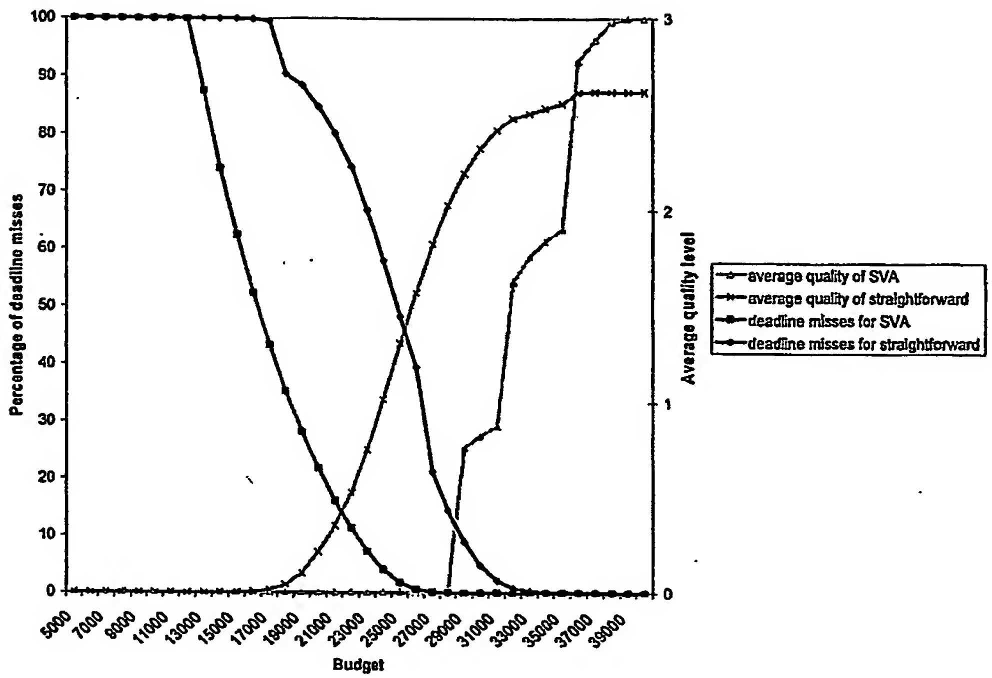


FIG. 4



100
90
80
70
60
50
40
30
20
10
0
Percentage of deadline misses
3
2
1
0
Average quality level
average quality of SVA
average quality of straightforward
deadline misses for SVA
deadline misses for straightforward
5000
7000
9000
11000
13000
15000
17000
19000
21000
23000
25000
27000
29000
31000
33000
35000
37000
39000
Budget

FIG. 6

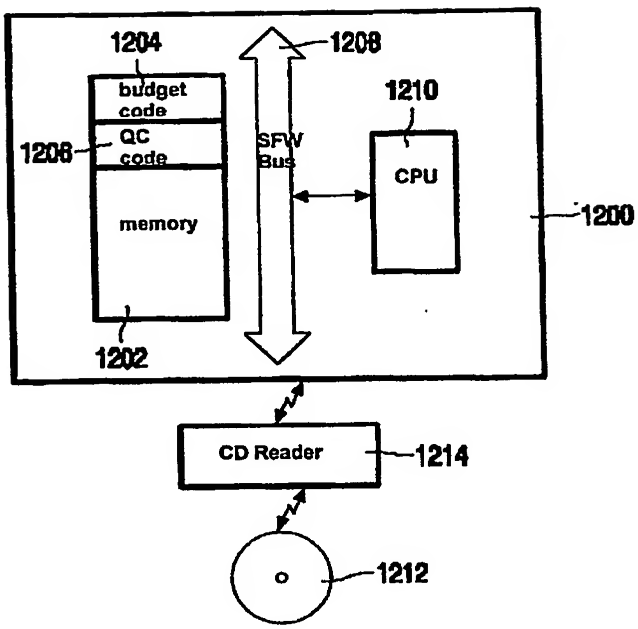


FIG. 8

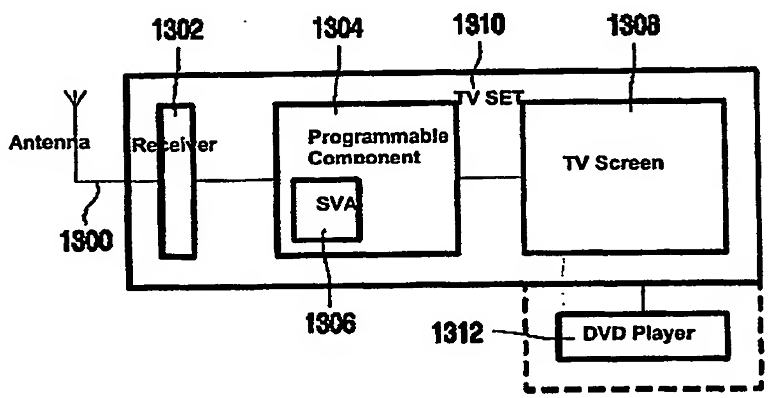


FIG. 9

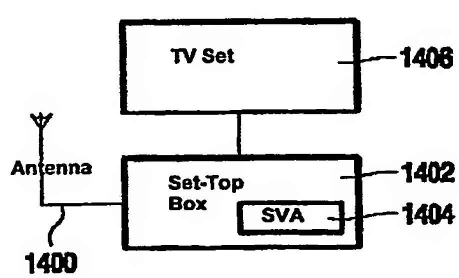


FIG. 10